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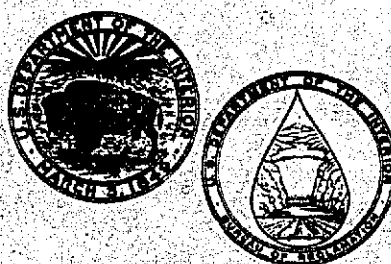
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# **INSTRUMENTATION FOR HYDRAULIC MEASUREMENTS IN LABORATORY AND FIELD STUDIES**

**Report No. HYD-592**

HYDRAULICS BRANCH  
DIVISION OF RESEARCH



OFFICE OF CHIEF ENGINEER  
DENVER, COLORADO

MAY 1969

HYD 592

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**INSTRUMENTATION FOR HYDRAULIC  
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**by  
J. C. Schuster**

**May 1969**

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**UNITED STATES DEPARTMENT OF THE INTERIOR \* BUREAU OF RECLAMATION**  
**Office of Chief Engineer . Denver, Colorado**

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## ABSTRACT

A collection of photographs and descriptive captions indicates some possible combinations of instruments used by the Hydraulics Branch of the Bureau of Reclamation. The described instrument combinations are not exhaustive, but show the capabilities of instruments purchased on a modest budget. One motive for selecting this equipment was the interchangeability of components. An instrumentation system assembled for a particular study may be reassembled into other systems for different investigations. The equipment includes measurement and recording systems for pressure, electric conductivity, temperature, velocity distribution, flow tracing, boundary shear, surge waves, wave height, and analog to digital conversion.

DESCRIPTORS--/ hydraulics/ \*instrumentation/ measurement/ conductivity/  
\*measuring instruments/ temperature/ pressure/ hydraulic conductivity/  
\*recording systems/ velocity meters/ velocity/ \*laboratory equipment/  
pressure measuring instruments/ pressure sensors/ \*hydraulic equipment/  
hydraulic models/ hydraulic transients/ hydraulic engineering  
IDENTIFIERS--/ instrument transformers/ analog instruments/ analog-to-  
digital converter/ pressure transducers

## INTRODUCTION

The purpose of this collection of photographs and descriptive captions is to indicate some of the possible combinations of instruments used by the Hydraulics Branch for data acquisition and analysis. The combinations described are not exhaustive but show the capabilities of instruments purchased.

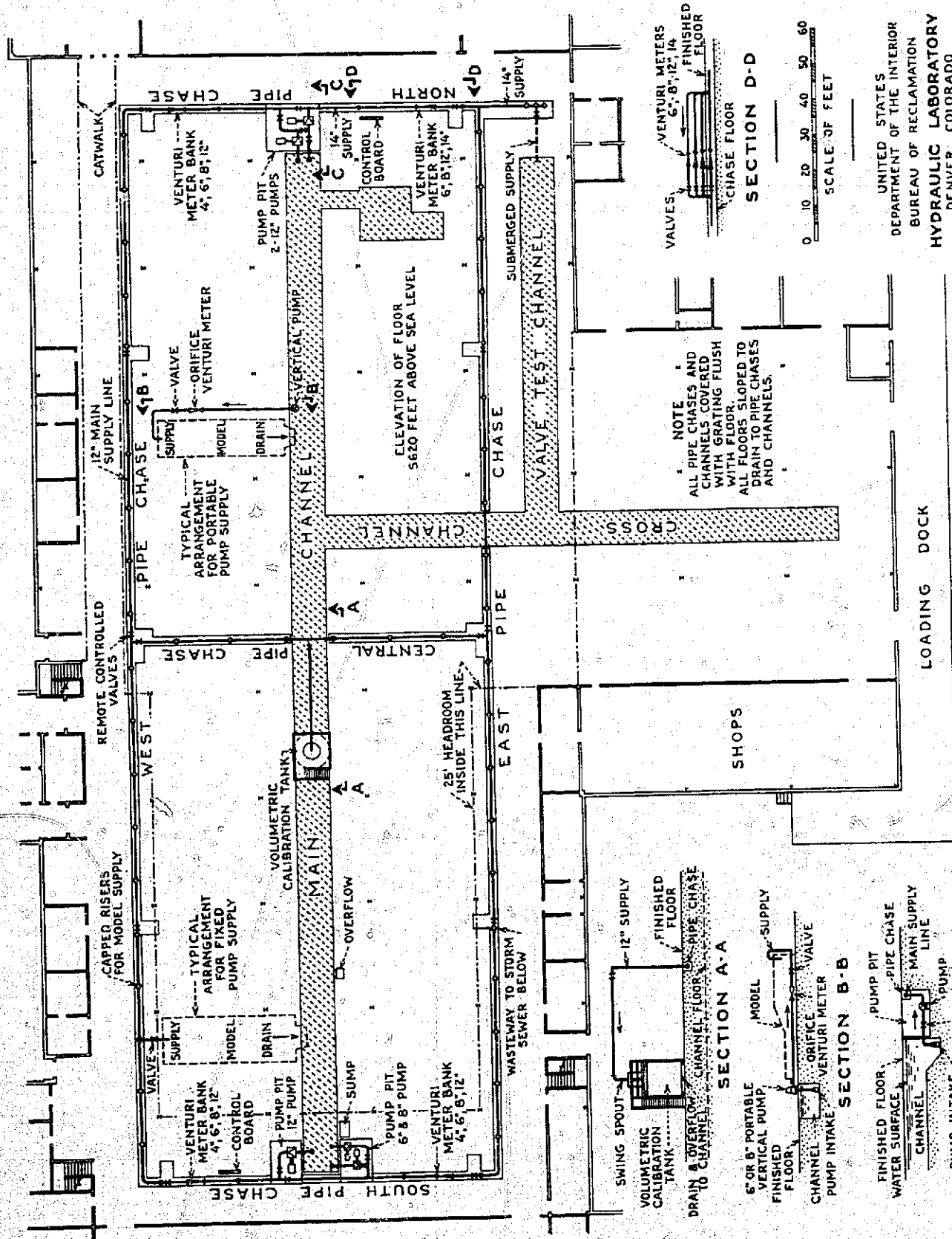
Interchangeability of the equipment was a motive in making the selections. When available, mountings for the equipment were chosen to permit assembly of systems in instrument racks. A system may thus be assembled from individual instruments for a particular study. Upon completion of the study, the components can be reassembled in other systems.

Components are chosen to be suitable for a variety of signal levels and not for a particular sensor. Thus, components may be used for conditioning the signal from a resistive, reluctance, piezoelectric, piezoresistive, or other types of sensors. Selection of the signal conditioning components has included consideration of future application to computer programming and data analysis. Some of the equipment is specialized but components of the specialized equipment can be used in other systems.

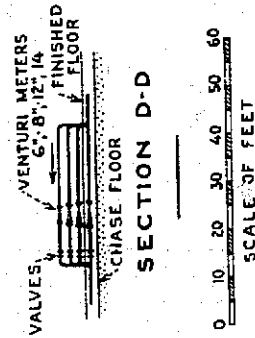
Recorders are selected according to information required from the study. Both analog and digital forms are available in direct-writing, digital tape, and FM magnetic tape recordings. The equipment has the capability of converting from analog to digital and digital to analog information.

Because of rapid changes of technology in the electronics field, purchased instruments do not usually contain the latest developments. This means that careful selection of the instruments is necessary to make them useful over an extended number of years and prevent early obsolescence.

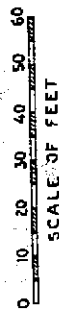
DESCRIPTIONS OF  
INSTRUMENTATION



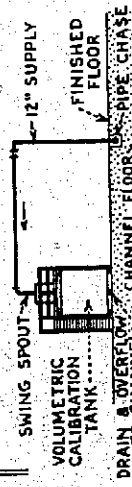
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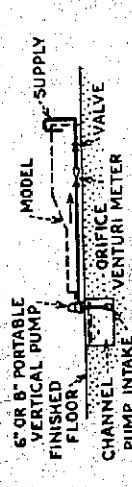
NOTE:  
 ALL PIPE CHASES AND CHANNELS COVERED WITH GRATING FLUSH WITH FLOOR. ALL FLOORS SLOPED TO DRAIN TO PIPE CHASES AND CHANNELS.



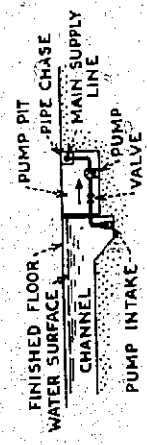
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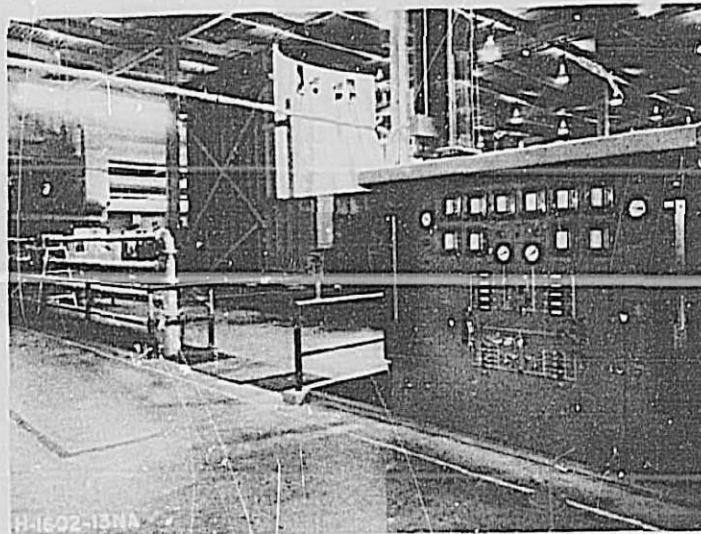
SECTION A-A



SECTION B-B



SECTION C-C



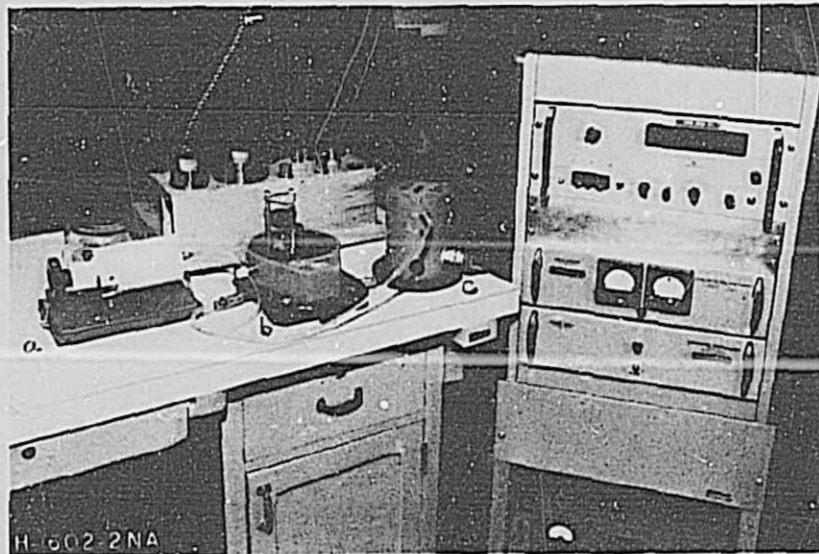
#### LABORATORY WATER SUPPLY

Water supplied to the north half of the Hydraulics Laboratory is controlled by the systems at the right of the picture. Water is routed to the left or right from two 10 cfs pumps located behind and under the control panel. Calibrated mercury manometers at each end of the board are used to indicate rates of flow or the flow may be read and indicated on the recorders near the top of the panel. The panel contains lights and indicator needles to show condition of operation of the control valves and venturi meters. Meters 14 to 4 inches and 12 to 3 inches are located on left and right of the panel. Equipment in the panel will eventually allow remote indication and control of laboratory models.

A frequency analyzer and direct-writing oscillograph are located near the model in the center of the picture.

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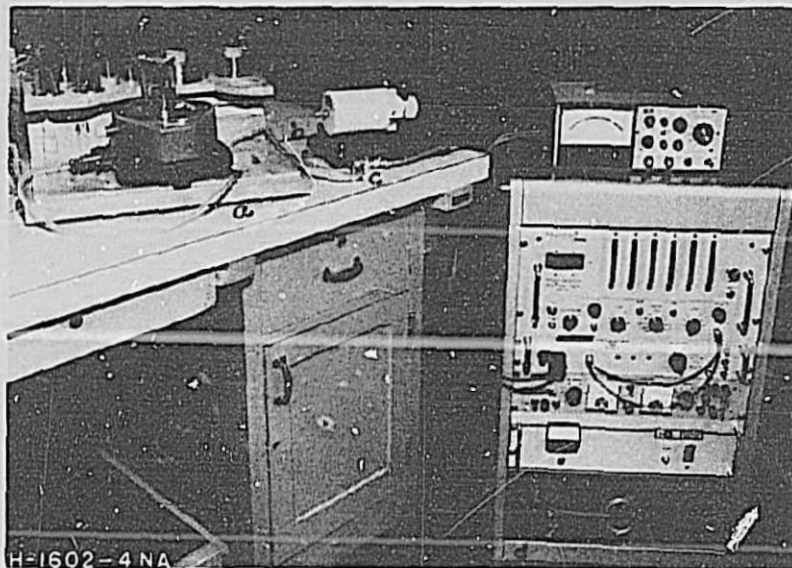
#### PRESSURE CALIBRATION

Pressure transducers may be calibrated over a pressure range of 0.3 to 500 psi. Assembled equipment (left to right):

- a. Pressure volume controller permits fine adjustment of air or nitrogen source pressure.
- b. Primary standard air-dead weight tester, piston and weight components behind tester.
- c. Secondary pressure standard (high-precision bellows-type pressure transducer).
- d. Instrument rack, for secondary pressure standard bottom to top, voltage regulator, power supply, servo amplifier and integrating digital d-c voltmeter.

Digital voltages representing pressures in psi, feet of water, or other units may be read from the voltmeter. The voltmeter may be used as the readout device for the pressure transducers used in field and laboratory studies.

PX-D-63952



#### PRESSURE TRANSDUCER CALIBRATION

A pressure transducer is being calibrated with primary standard dead weight tester. The electrical analog output of the transducer is converted to a digital reading. Equipment (left to right):

- a. Precision air-dead weight tester with piston and weights (0.3 to 500 psi) to background.
- b. Pressure Volume Controller for fine adjustment of air or nitrogen source pressure.
- c. Transducer on table top connected between tester and PVC.
- d. Instrument rack (bottom to top), drawer, voltage regulator, d-c power supply not in use, 100,000 Hz voltage to frequency converter to change analog signal from transducer to a frequency proportional to input voltage, and an events per unit time (E/put) meter used to count the cycles received from the voltage to frequency converter. Unit on top of the rack is a carrier-amplifier to provide the signal conditioning voltage for the transducer. The transducer and instrument rack after calibration are used for pressure measurement.

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#### PRESSURE MEASUREMENT

Servomanometer system being used to measure air pressure. Equipment from left to right, precision bellows type transducer (+1.5, +5, +15, and +30 psi available in Hydraulics Branch); digital tape, 11 column, 5 lines per second printer; instrument rack (bottom to top); voltage regulator, servo-power supply; servoamplifier; and digital voltmeter. Displacement of bellows in the transducer is caused by application of pressure. A voltage is applied by the servosystem to inductive coils in the transducer. The force applied is just sufficient to return the bellows to a null position. The voltage required to apply the force represents the pressure applied to the transducer. The digital voltmeter displays the voltage and transfers the reading to the printer.

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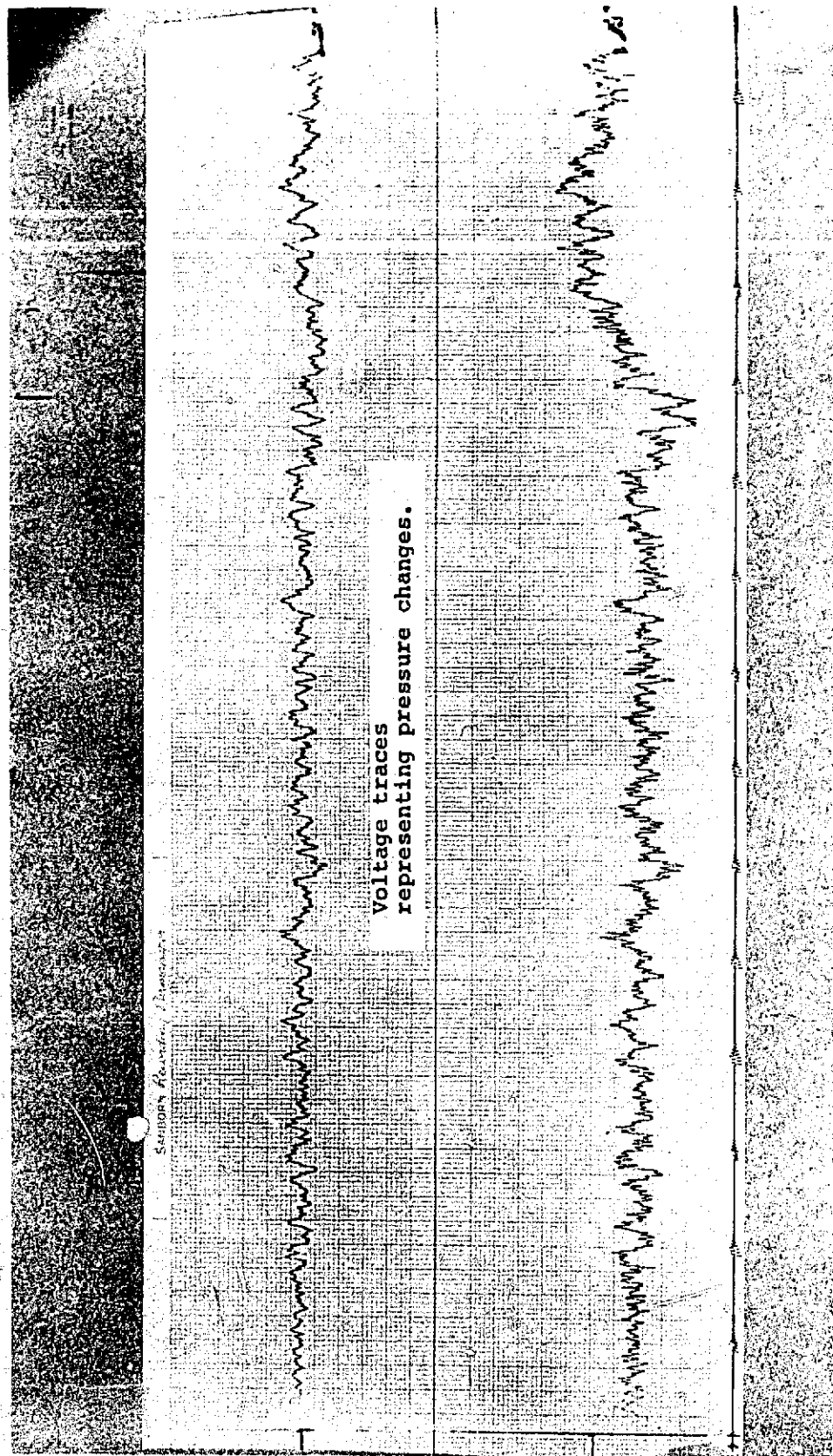
#### PRESSURE MEASUREMENT AND RECORDING

Simultaneous measurement of the pressures along the inlet of a pipe was required to find the loss of head.

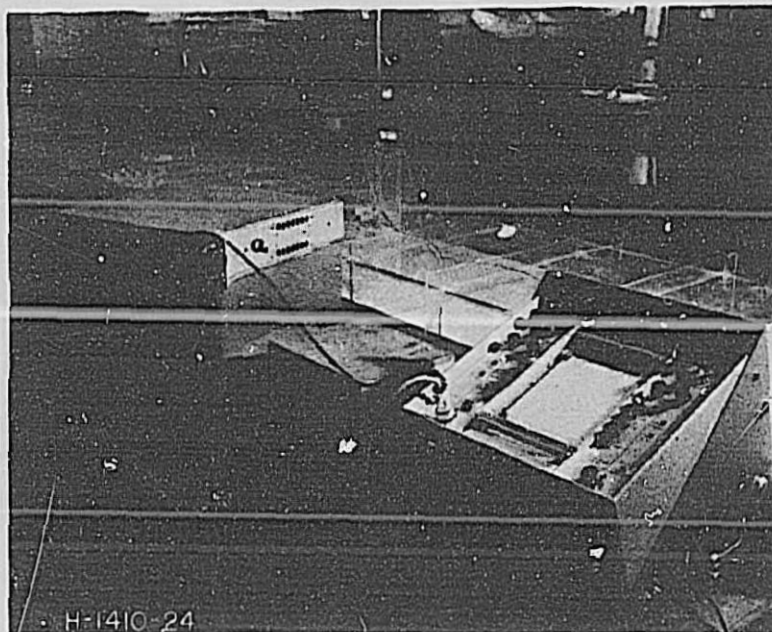
An eight-channel recorder using heated styli for direct writing made an analog record of the voltage from pressure transducers. The pressure transducers were energized by the carrier-amplifiers of the recorder.

To increase the accuracy of measuring the head loss, one differential transducer was connected between the pressure upstream of the inlet entrance and a piezometer ring downstream in the pipe. The transducer was supplied a 2,400 Hz 5-volt signal by the carrier-amplifier on top of the center instrument rack. The output of the amplifier was digitized by the integrating digital voltmeter just below. A signal from the voltmeter, representing the pressure difference, was recorded on the tape printer to the right. The oscillator on top of the printer was used to control the time of voltage integration.

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#### PRESSURE TRANSDUCER INSTRUMENTATION

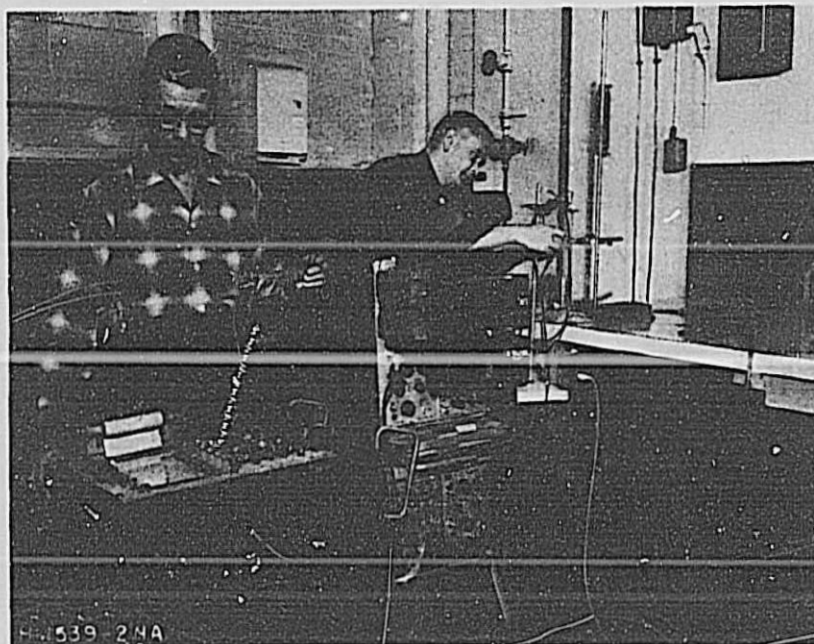
The velocity head was measured as the differential pressure between a total head tube attached to the point gage and a piezometer head in the wall of the conduit.

The pressure transducer was thermally isolated in the wooden box at the center of the instrumentation group. The transducer, a differential transformer type, had an operating pressure range of +0.8 psi. A 5-volt, 2,400 Hz carrier-amplifier powered the transducer from the direct-writing recorder on the right. An analog chart of the varying direct current output of the transducer was made by recorder.

The direct current from the transducer was made the input to a digitizing system on the left. Voltages, representing the differential pressure across the transducer, were fed as an input to a (a) voltage-to-frequency converter.

The converter has a linear 100,000 Hz output for the full range of 4 input scales 0.1-, 1.0-, 10-, or 100-volt input. The frequency or pulse output of the converter, proportional to a fraction of the 100,000 Hz, was registered on an (b) event per unit time (E/put) meter and then recorded manually or on a digital tape printer (not shown in photograph).

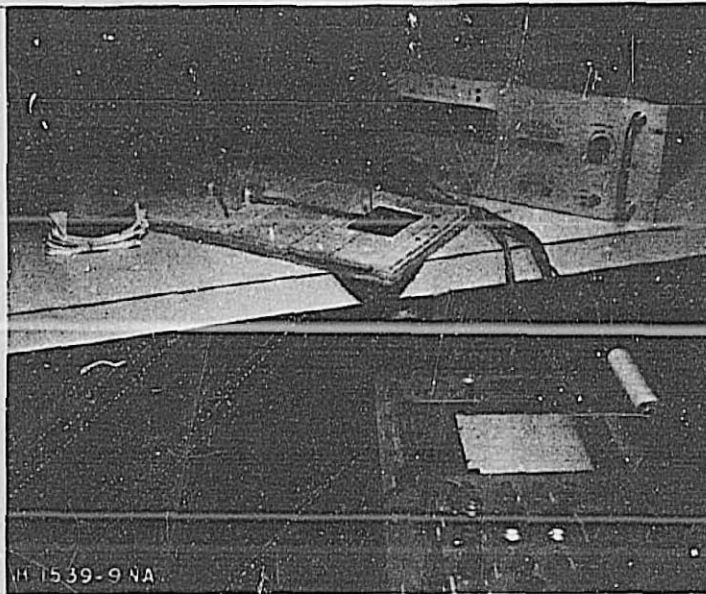
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#### FREQUENCY RESPONSE OF TRANSDUCER PRESSURE LEADS

Amplification or attenuation of pressures can be caused by the system used for the measurement. A shock tube, a device for applying a pressure pulse to a transducer system, is used to help measure the response of a pressure transducer and pressure lead. The hands of the man near the wall are on the shock tube partially filled with water. The pressure lead exits to the right near the bottom of the tube. The transducer is held in the vice on the table top at the end of the transducer lead. The transducer electrical output is connected to (left to right) a direct writing oscillograph and an oscilloscope equipped with Polaroid camera. The shutter release trips a relay on the shock tube to apply a pressure to the transducer, the camera photographs the trace on the oscillograph, and the recorder provides a separate trace of the electrical signal from the pressure transducer. Computations from data taken from trace establish the frequency and pressure response of the transducer and lead.

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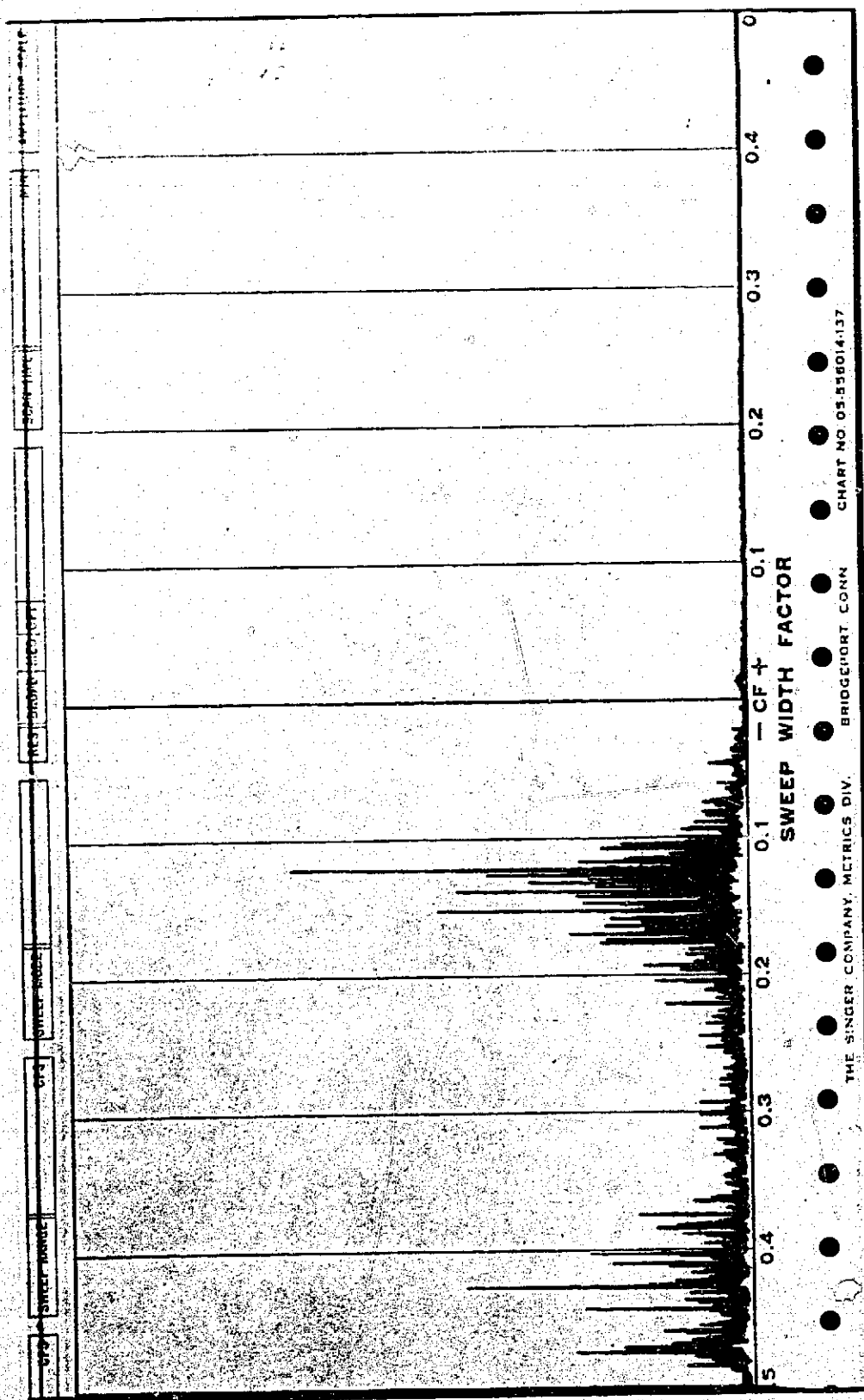


#### ANALOG TO DIGITAL CONVERSION

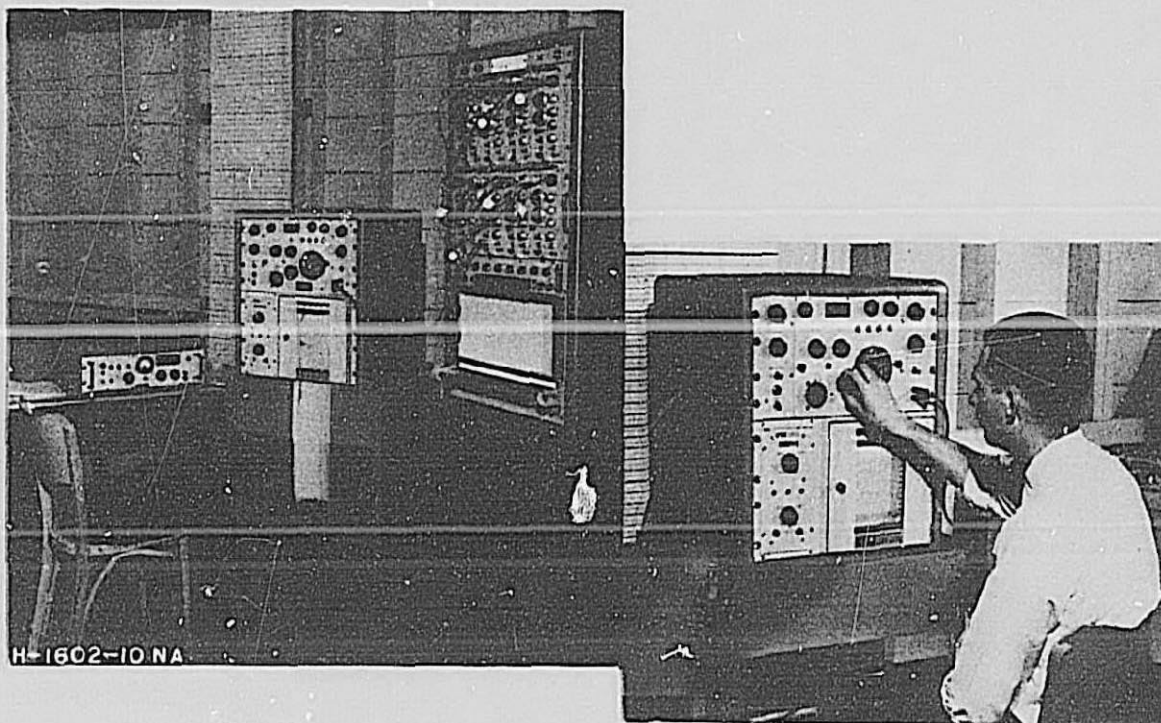
An analysis was required of the data from a photographic record of the change of electrical output of a pressure transducer. A computer requiring digital input was used for the analysis. Digital data from the photograph was obtained from a Linear Variable Differential Transformer and digital voltmeter. On the table near the center the LVDT is clamped under the two plastic blocks near the back of the plywood support. The core of the transformer is attached to a pointer over the photographic record near the right end of the plywood. The record is manually followed with the pointer and voltages from the LVDT are measured by the digital voltmeter to the right. Thus the analog form of the record was converted to a digital representation. The instrument in the foreground of the picture supplies the signal conditioning voltages for the LVDT.

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Example of frequency analyzer output chart.



#### ANALYSIS OF RANDOM VOLTAGE SIGNALS

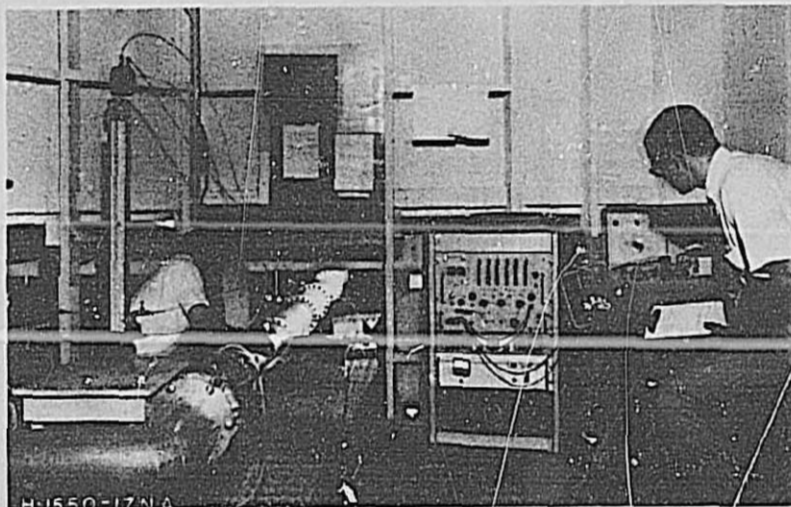
Analysis of the mixture of voltage amplitudes and frequencies from model and prototype studies can be useful in structural design. Two methods of analysis can be used: (1) The data can be digitized and processed by computer, or (2) the data can be converted by an analog device. The analog converter, or Frequency Analyzer, spectrum and spectral density components, are shown in the photographs at the center and left.

Fluctuating pressures from a model were converted to voltages by pressure transducers. The transducer signals were amplified by the circuits of a direct-writing oscillograph. The signal could be recorded and simultaneously fed, a single channel at a time, to the spectrum analyzer and a spectral density analyzer. The analyzer relates the amplitude and frequency over a range of about  $1/2$  to 2,500 Hz. The spectral density analyzer relates the average or peak value of the voltage (pressure representation) to a given frequency, or the integral of the voltage or power over a selected frequency interval.

The analyzer uses a heterodyne principle to produce the spectrum of the frequencies present in the transducer signal. A frequency band may be selected for analysis by setting plus and minus limits on a selected center frequency. A 500-, 100-, or 20-Hz linear segment may be centered between 0 and 2,250 Hz. A 50-, 10-, or 2-Hz linear segment may be centered between 0 and 225 Hz.

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PX-D-63028





#### CONDUCTIVITY MEASUREMENT (SYSTEM 1)

A two electrode probe was used with the instruments shown to measure conductivity of the flowing water containing a low concentration of sodium chloride.

The conductivity probe is supplied with 5 volts at 2,400 Hz by the carrier amplifier of a direct-writing recorder (right). The analog voltage from the probe, representing the change of conductivity, is recorded and simultaneously fed to a voltage to frequency converter (center of instrument cart). The converter has a linear 100,000 Hz output for full range of 4 input scales, 0.1-, 1.0-, 10-, or 100-volt input. The frequency or pulse output of the converter, proportional to a fraction of the 100,000 Hz, was registered for a selected time on an event per unit time (E/put) meter (top of instrument cart) and then recorded on a digital tape printer in the background.

The system was calibrated for about 0 to 80 ppm of dissolved sodium chloride.

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E22A08/30

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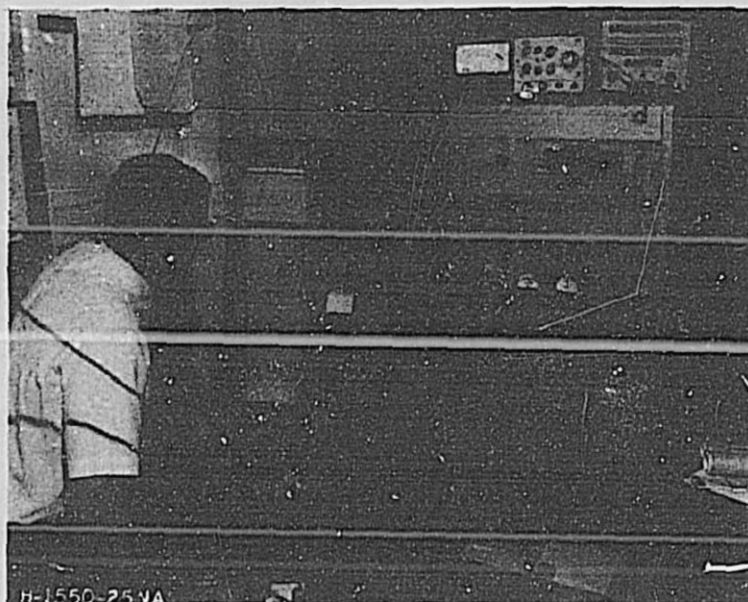
1	9	5	6	2
1	5	8	1	8
2	4	9	8	2
3	1	2	3	2
3	9	5	7	6
4	2	2	5	7
3	5	5	3	6
2	7	4	2	3
1	1	6	0	5
1	2	8	0	1
1	1	7	2	1

1	0	3	7	1
1	4	9	3	0
2	0	1	3	6
2	6	2	9	0
3	8	1	2	3
4	1	3	6	9
4	0	1	8	5
3	2	2	2	0
2	5	2	5	1
1	8	8	5	2
1	5	0	8	1

-0 0 4 9

E22A08/30

Example of printed tape prepared for  
key punch use.



#### CONDUCTIVITY MEASUREMENT (SYSTEM 2)

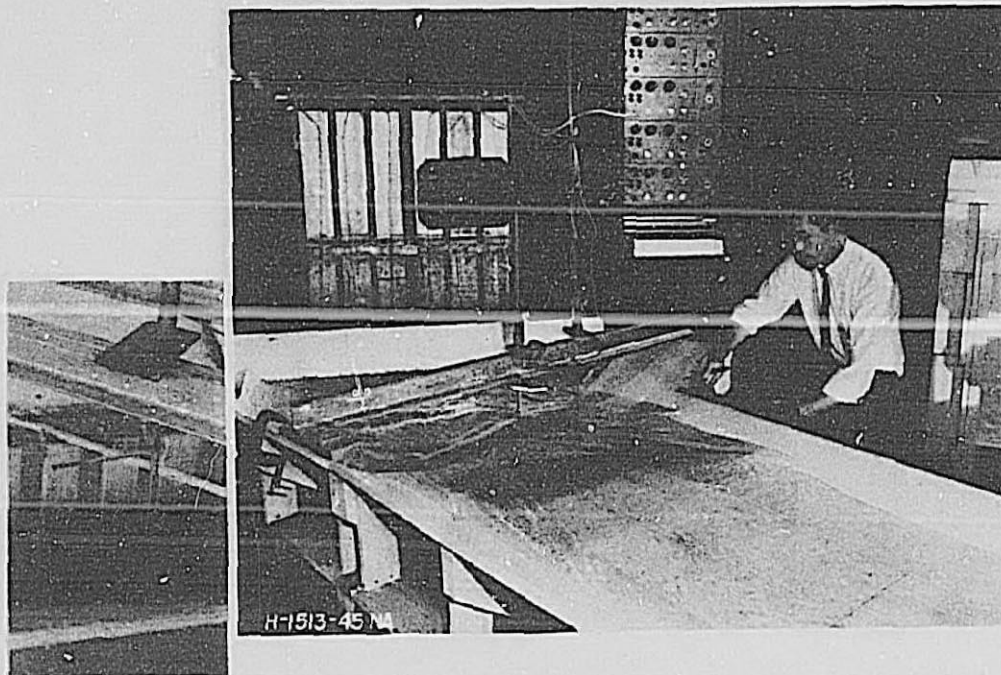
A two electrode probe was used with the instruments shown to measure the conductivity of a low concentration of sodium chloride in water flowing in a pipe.

The probe was supplied with a 5-volt, 2,400 Hz signal from the carrier-amplifier (a). The output of the amplifier (the voltage representing the change of conductivity) is recorded in analog form on the high impedance voltmeter (b) or is fed to an integrating digital voltmeter (c). An oscillator (d) was adjusted to time the input of the digital voltmeter for selected periods. The integrated voltage or digital count is displayed by the voltmeter and transferred by the voltmeter to a digital printer (e). The two instruments in the lower part of the right-hand rack were not in use.

The system was calibrated for solutions containing about 0 to 80 ppm of sodium chloride.

PX-D-63961





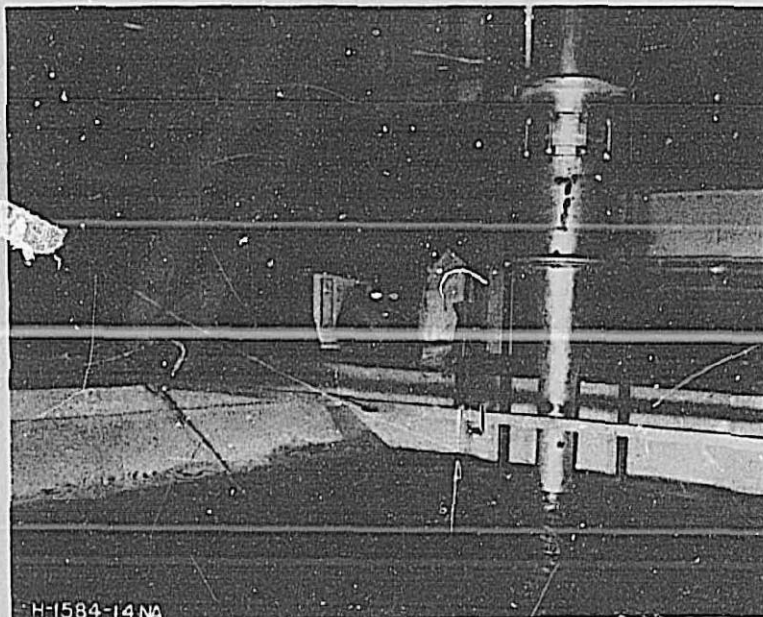
#### SURGE WAVE MEASUREMENT

Wave heights were measured for surges caused by the rapid rejection of flow from simulated pumping plant in a trapezoidal canal.

Six capacitance-type wave probes (one shown here on right side of support) were made from plasticized enamel-coated wire. The wires were about 6 inches long and mounted in a U-shaped frame made of 1/4-inch stainless steel rod. The frame is attached to a point gage support for calibration of the probe and for wave measurement. Each wave probe can be connected to one channel of a six-channel direct-writing recorder.

The sensors are calibrated by moving them vertically an accurately measured distance in still water while charts of the voltage change are made on the recorder.

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PX-D-63962



#### WAVE HEIGHT AND FREQUENCY

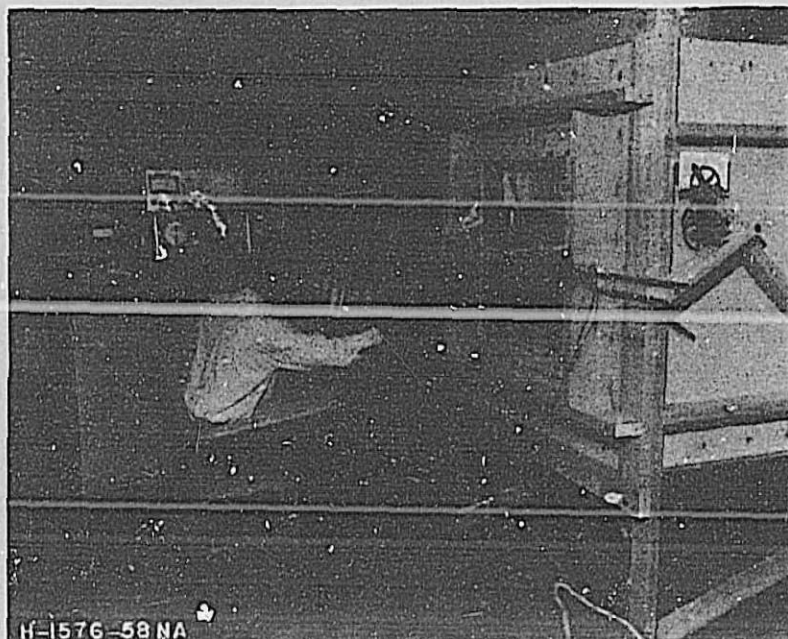
Effectiveness of the energy dissipation by a vertical stilling well was indicated by the height of residual waves in the discharge channel.

The instrumentation included two capacitance-type wave probes with sensors of plasticized enamel-coated copper wire. Each wire was about 6-1/4 inches long, mounted in a U-shaped frame made of 1/4-inch stainless steel rod. The frame is held in a point gage support (near center and at left side of photograph). Each wave probe was connected to one channel of a dual channel, direct-writing recorder.

The sensors are calibrated by moving them an accurately measured distance in still water while charting the change of voltage on the recorder. The probes have a near linear relationship of immersion depth versus voltage when the water remains near the center 2 inches of the wire sensor.

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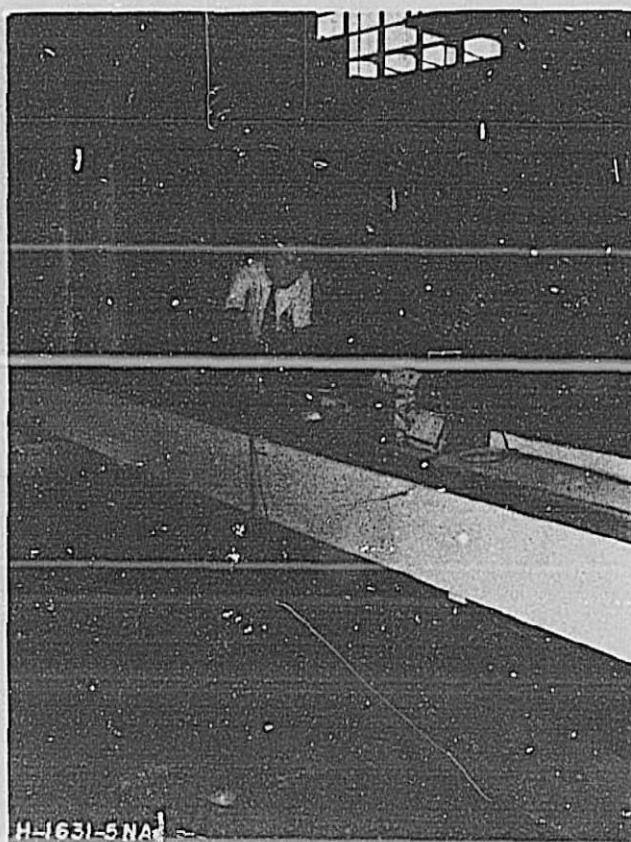


#### CONSTANT TEMPERATURE ANEMOMETER SYSTEM

The anemometer modules and power supply (top instrument to left) used in a draft tube surge study can measure velocity, mass flow, turbulence and correlations, pressure, temperature, and other fluid flow changes. Associated in the study were a retentive oscilloscope and a direct-writing oscillograph. All instruments were portable. The recorder was used with a pressure transducer to measure pressure fluctuations. The oscilloscope could be used to observe the output of the anemometer before recording.

The constant temperature anemometer includes a hot-wire or hot-film sensor located in the fluid. This sensor is connected as part of a resistive bridge in the anemometer module. Because the bridge output is nonlinear, a linearizer circuit has been added to the anemometer. The system will accept the input from 4 sensors but only 3 anemometers have been acquired in the system shown. The anemometers are wide-band low-noise amplifiers having a linearized frequency response up to 200 KHz. A 400 KHz frequency response can be obtained for the basic (nonlinear) anemometer. The instrument may be used with a single sensor or multisensor probes in X, parallel, or 3 mutually perpendicular configurations. The system is designed primarily for use in air but can be easily converted for use in water.

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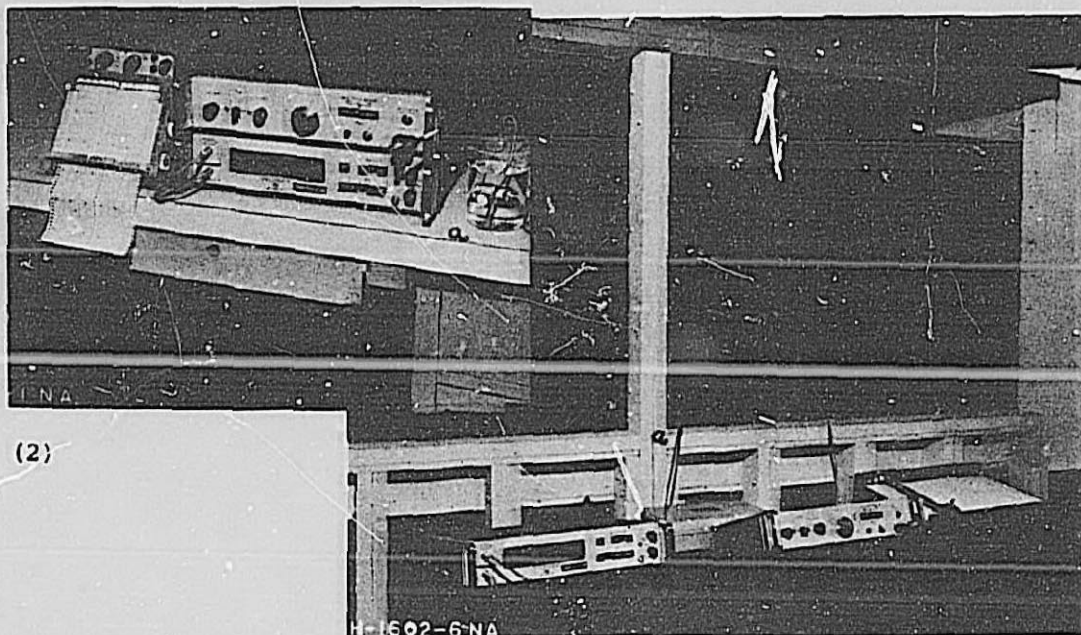


#### FLOW TRACING AND MEASUREMENT

Fluorescent dyes can be used for discharge measurements, flow distribution, water quality, and stratified flow studies. The fluorometer at the center of the instrumentation group measures tracers such as fluorescein, rhodamine, and pontacyl dyes in the micromilliliter (ppm) or in the nanomilliliter (ppb) ranges. The fluorometer is basically an optical bridge analogous to a wheatstone bridge. The optical bridge measures the difference between light emitted by a sample and that from a calibrated light path. Either discrete samples or continuous flow samples of the traced fluid may be measured by the fluorometer. In the illustration, a continuous dye sample was being pumped through the fluorometer and recorded on a strip chart voltmeter. The fluorometer has a direct reading dial graduated from 0-100 parts that may be used for monitoring the sample or for manual recording of the data. The output voltage of the fluorometer may also be digitized by a voltmeter, printed on tape, or punched on tape.

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(2)

(1)

#### TEMPERATURE MEASUREMENT (Quartz Crystal)

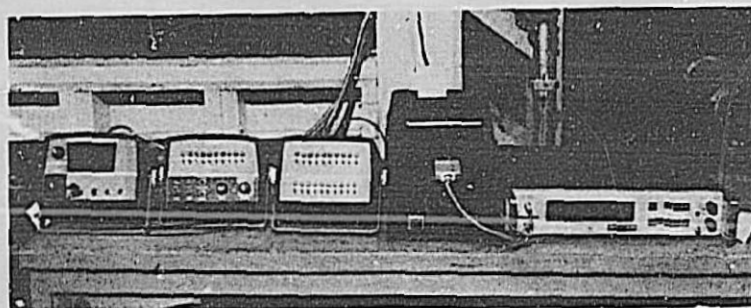
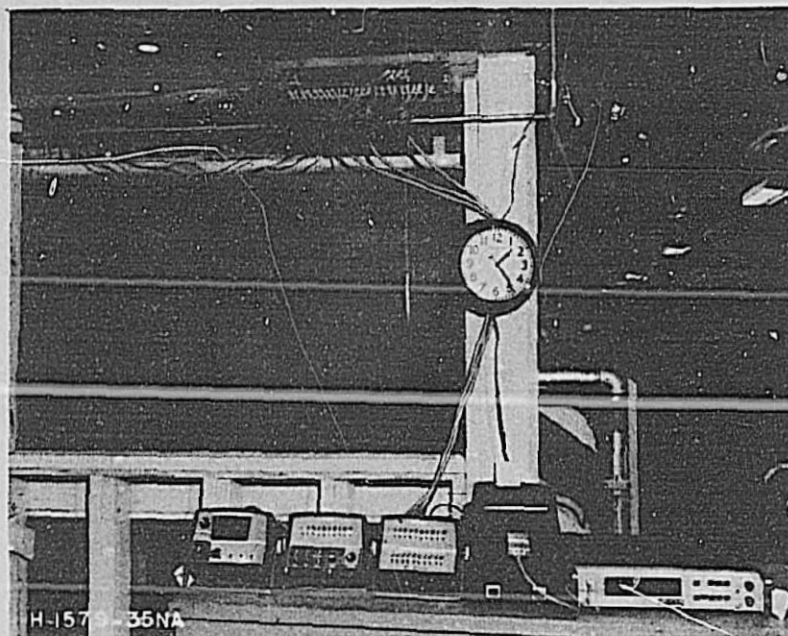
Precise measurement of temperature is necessary when differences in water density are used to study stratified flow.

The digital thermometer on the left of the table (Photograph 1) uses the sensitivity of the resonant frequency of a quartz crystal to temperature change. The thermometer is equipped with two sensing probes (a, b) for measuring temperature at either probe or the difference between the two (near top and bottom of tank). A 6-digit visual readout and recording output has push-button-controlled sample times to provide resolutions of 0.01, 0.001, or 0.0001° C. The instrument shown has a temperature range of measurement between -80° to +250° C.

Output from the thermometer may be read from the digital display or recorded from the output of a digital to analog converter. The converter and an X-Y plotter are the center and right instruments on the table. The D/A converter will handle a single temperature measurement or the difference measured between the two probes. A real or scaled time can be applied to the X-Y plotter to graph the change of temperature.

The second photograph shows the system in use with a high-impedance recording voltmeter.

(1) PX-D-63967  
(2) PX-D-63966

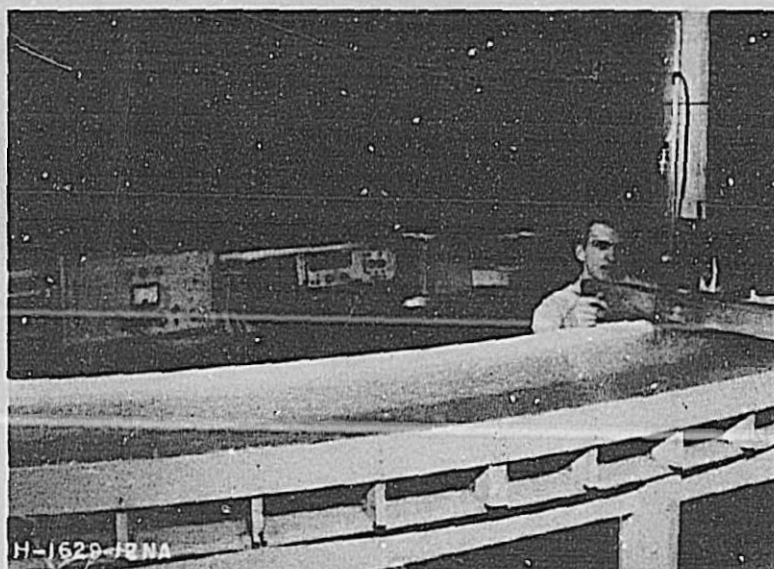


#### TEMPERATURE MEASUREMENT (Thermistors)

Multiple-point temperature measurement for density stratified flow studies uses a system of matched thermistors. The thermometer range of  $0^{\circ}$  to  $20^{\circ}$  C is directly read to four significant digits (instrument to left). The last significant digit is graduated with scale divisions for increased reading resolution, e.g., 15.14(2). The instrument accuracy is  $\pm 0.05^{\circ}$  C and the calibration can be confirmed or corrected by front panel controls. Calibrations are performed with the quartz thermometer (right side of the table). A 10-point master and 20-point auxiliary scanner are used with the thermometer (center). All temperature sensors are scanned unless they are selectively omitted by individual switches. As each point is activated, matching logic is made available in 1248 BCD form. The temperature is displayed on the thermometer or may be recorded on the tape of a digital printer (beneath clock). The printer has available sensor identification, temperature printout, and can be given external (manual or programed) print commands.

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PX-D-63969





#### VELOCITY DISTRIBUTION MEASUREMENTS

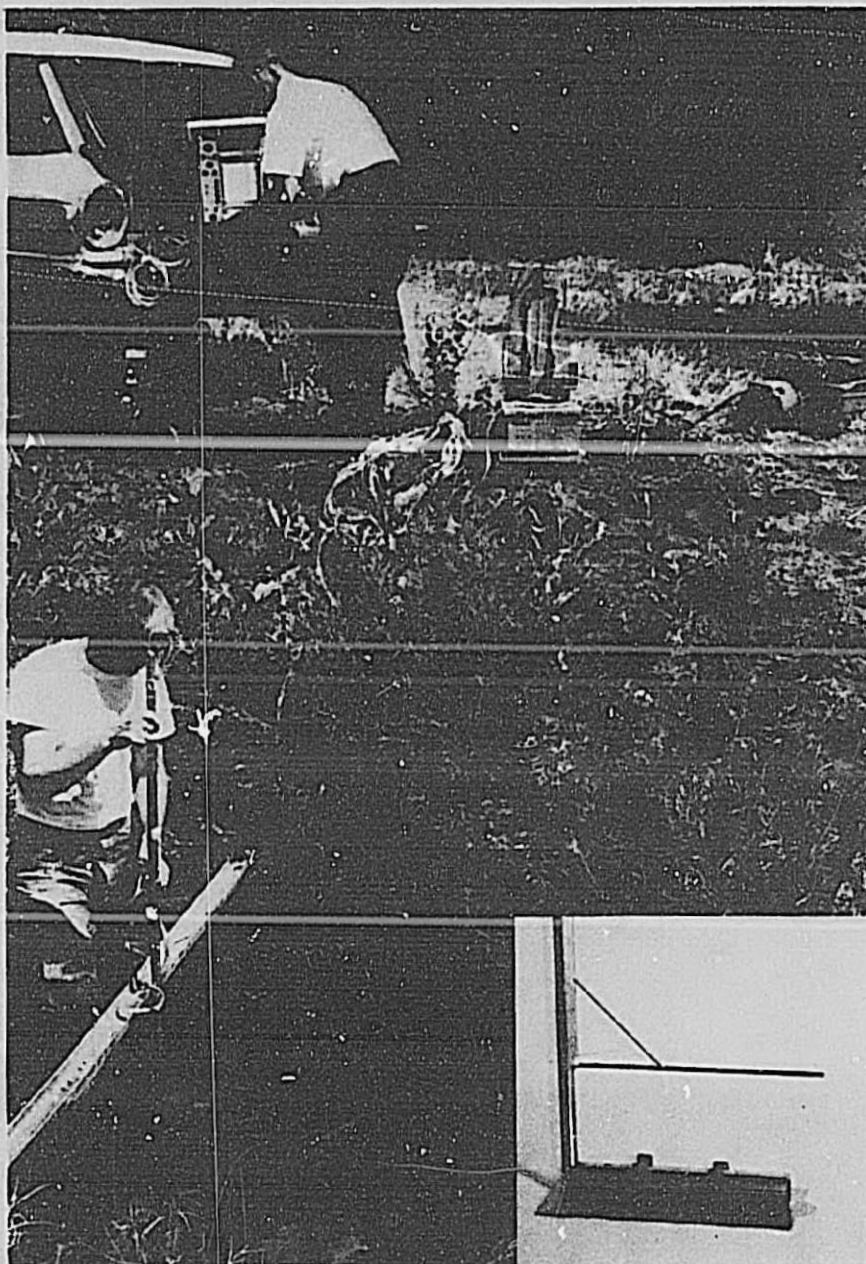
Velocities of waterflow in a trapezoidal channel are being measured with a miniature propeller meter.

The 1-cm-diameter 5 blade propeller made of plastic is suspended in jewel bearings on a stainless steel support. A gold electrode in the same support is mounted close to the passing tip of the propeller blades. A resistance change caused by the short water path between the electrode and tip produces a voltage pulse in a counting unit.

The counting unit, placed on the table to the left, in normal operation counts the voltage changes for a period of time. An internal circuit counts for a 10-second period and then displays the number on a "glow tube" dekatron counter of 999 counts capacity. The dekatron counter may also be timed manually using a stopwatch. The range of the instrument is 0.9 in./sec to 2 ft/sec (up to 5 ft/sec may be measured by counting each 1/1,000 pulse).

To increase the speed of reading and recording the counts from the propeller, a counter-timer (Systron Donner) was substituted for the dekatron "glow tube" display. The input to the "glow tube" counter was transferred to the counter-timer and is displayed on a 6-digit-in-line indicator panel. The counter also transfers the counts to a tape printer on the right end of the table.

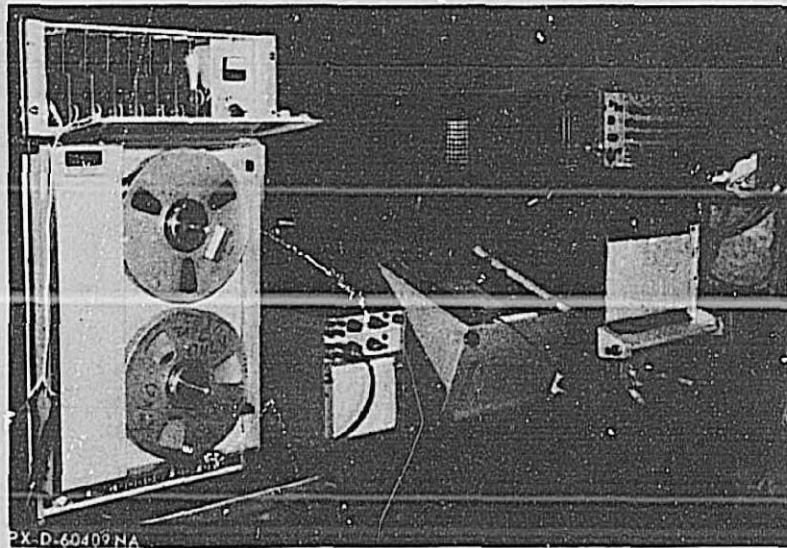
The counter-timer may be employed with suitable input transducers and plug-ins for measuring frequency, relay and switch timing, viscosity, elasticity, tachometry, telemetry, pulse height and width, flow, strain, force, pressure, and radiation. The Hydraulics Branch counter can be converted into an integrating digital voltmeter, peak voltage meter, and interval timer. Plug-ins are available for other functions. The printer can be associated with a number of systems and can provide 9 columns of a maximum of 18 at a maximum rate of 20 lines per second.



#### BOUNDARY SHEAR MEASUREMENTS

Boundary shear measurements are made on field canal boundaries using a Preston shear tube (a type of pitot tube) constructed in the laboratory for field canal depths. A pressure transducer is used to convert the pressure differential to electrical signals recorded by a direct-writing oscillograph. The Preston tube is held by the man in the stream, the transducer is placed in the box (photograph center) for temperature control, and the recorder is located in the station wagon. A water manometer calibration device stands behind the pressure transducer box. The recorder values of pressure are converted to shear values by use of a calibration curve. In the field a gasoline electric generator with a voltage regulator is used to supply power to operate the recorder.

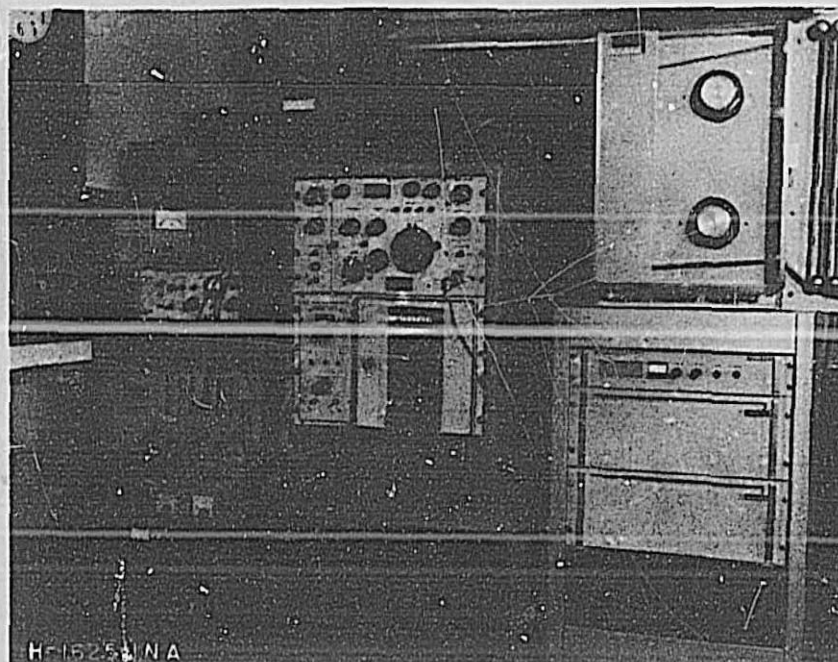




#### MAGNETIC TAPE AND DIRECT-WRITING PRESSURE RECORDING

Arrangement of instruments for pressure distribution measurements in the outlet works stilling basin - Yellowtail Dam, Montana. Both magnetic tape and direct-writing records were made of the output of seven pressure transducers and two accelerometers. The signal conditioning for the pressure transducers was supplied at 2,400 Hz by the preamplifiers at the upper right. The transducer output was recorded on the 8-channel, direct-writing recorder (Sanborn) lower right, and on the frequency modulated magnetic tape (left). The record/reproduce amplifiers for 7 channels of the 14-channel capacity of the recorder are on top of the recorder. The tape recorder has speeds of 1-7/8, 3-3/4, 7-1/2, 15, 30, and 60 inches per second. The bandwidth of frequency is from d-c to 10 KHz. Both the direct-writing and magnetic tape recorders and preamplifiers are portable for field use or can be rack-mounted for the laboratory. A 2-channel direct-writing recorder (Sanborn center) was used to condition and record the output from accelerometers. An Electronic 19, (Honeywell) high-impedance recording voltmeter (beside tape recorder) was used to monitor voltages in the system.

PX-D-60409

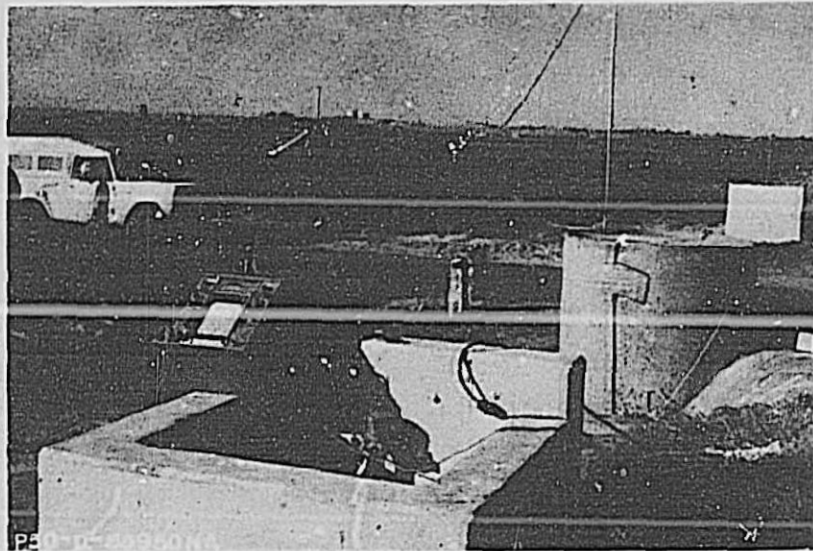


#### FREQUENCY ANALYSIS FROM TAPE LOOP

Recordings of pressure, vibration, acceleration, etc., on magnetic tape may be analyzed from a tape loop. The loop, between 6 and 30 feet in length, is cut from the recorded tape. The extracted section is looped on rollers attached to a plate fastened to the recorder (right of photograph). The tape is extended to the recorder and passes over the record and playback heads. A desired channel of information is selected and the output from a reproduce amplifier becomes the input to the frequency analyzer. The loop may be used through the reproduce amplifiers for oscilloscope viewing, or recording of single or multiple channels.

PX-D-63972



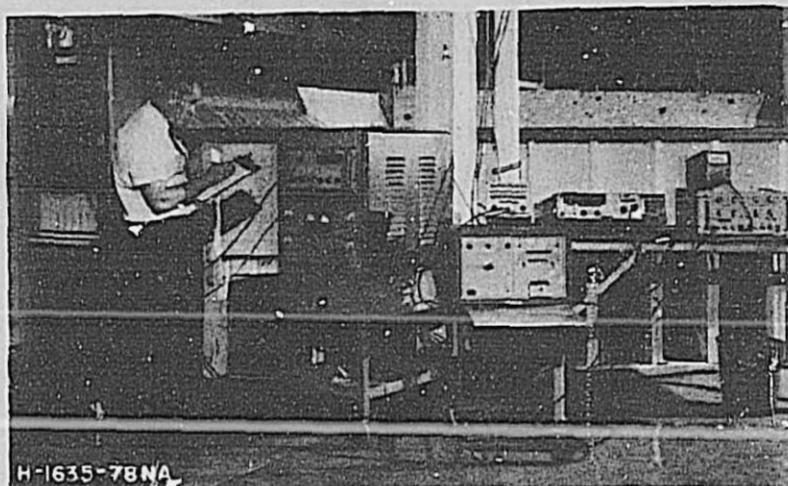


#### PIPELINE PRESSURE MEASUREMENTS

Pressure measurements were required in the pipeline and in the bonnet of the turnout valve to determine the size of the pressure fluctuations occurring in the pipeline.

A two-channel direct-writing oscillograph was used to record the output of two 5 psid pressure transducers. One of the transducers was mounted in a pitot tube inserted into the downstream end of the pipe entering the left side of the pipe stand. The second transducer was attached by a 10-foot pressure lead to the bonnet of the valve in a pit near the base of the stand. Records were made of the pressure fluctuation in the pipe as the valve was opened and closed to deliver water through the structure supporting the recorder.

P50-D-55950NA



### TURBULENCE IN ENERGY DISSIPATION

In studies of energy dissipation, a statistical relationship was desired to describe the mean and fluctuating components of pressure on the floor of a stilling basin. **Piezometers** in the floor of the basin were connected to pressure transducers. An analog recording of the pressures was made on a direct-writing, eight-channel recorder for frequency and amplitude. Two instrument systems producing digital information were used to provide the statistical analysis.

The signal from a transducer-amplifier (recorder behind the engineer) was selected for both the input to a voltage averaging system and the input to a system extracting the root-mean-square of the fluctuating component of the signal. Thus, the relationship between the static depth and the pressure fluctuation occurring on the floor was obtained from the basin.

The averaging system contained an integrating digital voltmeter (center rack, upper instrument). The total signal to the voltmeter was integrated for a time (200 seconds) controlled by the oscillator on top of the digital tape printer (cart to right of printer). The output of the voltmeter was then transferred to the printer. The average pressure level was then manually calculated from the integrated (volt-seconds) divided by the time of the integration.

The dynamic part of the signal was analyzed with the instruments on the table, a filter to the right, a root-mean-square voltmeter on top of the filter, and a second integrating digital voltmeter to the left. The signal from the transducer amplifier passed through the filter to the rms meter. The meter extracted the rms value of the fluctuating part of the total signal. The rms value was integrated for 200 seconds and then displayed on the voltmeter for manual recording. The filter was used to exclude a small amplitude signal produced by the 2,400-hz carrier-frequency of the transducer-amplifier.

# CONVERSION FACTORS--BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, January 1984) except that additional factors (\*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given on pages 10-11 of the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg; that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Table I

## QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
<b>LENGTH</b>		
Mill. . . . .	25.4 (exactly) . . . . .	Micron
Inches . . . . .	25.4 (exactly) . . . . .	Millimeters
	2.54 (exactly)* . . . . .	Centimeters
Feet . . . . .	30.48 (exactly) . . . . .	Centimeters
	0.3048 (exactly)* . . . . .	Meters
	0.003048 (exactly)* . . . . .	Kilometers
Yards . . . . .	0.9144 (exactly) . . . . .	Meters
Miles (statute) . . . . .	1,609.344 (exactly)* . . . . .	Meters
	1.609344 (exactly) . . . . .	Kilometers
<b>AREA</b>		
Square inches . . . . .	6.4516 (exactly) . . . . .	Square centimeters
Square feet . . . . .	929.03* . . . . .	Square centimeters
	0.092903 . . . . .	Square meters
Square yards . . . . .	0.836127 . . . . .	Square meters
Acres . . . . .	0.40469* . . . . .	Hectares
	4,046.9* . . . . .	Square meters
	0.0040469* . . . . .	Square kilometers
Square miles . . . . .	2.58999 . . . . .	Square kilometers
<b>VOLUME</b>		
Cubic inches . . . . .	16.3871 . . . . .	Cubic centimeters
Cubic feet . . . . .	0.0283168 . . . . .	Cubic meters
Cubic yards . . . . .	0.764555 . . . . .	Cubic meters
<b>CAPACITY</b>		
Fluid ounces (U.S.) . . . . .	29.5737 . . . . .	Cubic centimeters
	29.5729 . . . . .	Milliliters
Liquid pints (U.S.) . . . . .	0.473179 . . . . .	Cubic decimeters
	0.473168 . . . . .	Liters
Quarts (U.S.) . . . . .	946.358* . . . . .	Cubic centimeters
	0.946331* . . . . .	Liters
Gallons (U.S.) . . . . .	3,785.43* . . . . .	Cubic centimeters
	3.78543 . . . . .	Cubic decimeters
	3.78533 . . . . .	Liters
	0.00378543* . . . . .	Cubic meters
Gallons (U.K.) . . . . .	4.54609 . . . . .	Cubic decimeters
	4.54596 . . . . .	Liters
Cubic feet . . . . .	28.3180 . . . . .	Liters
Cubic yards . . . . .	764.55* . . . . .	Liters
Acre-feet . . . . .	1,233.5* . . . . .	Cubic meters
	1,233,500* . . . . .	Liters

Table II  
QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb.)	64,798.91 (exactly)	Milligrams
Troy ounces (480 grains)	31,103.48	Grams
Ounces (avoirdupois)	28,349.52	Grams
Pounds (avoirdupois)	453.59237 (exactly)	Kilograms
Short tons (2,000 lb.)	907.185	Kilograms
Long tons (2,240 lb.)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
Pounds per square foot	0.089476	Newtons per square centimeter
Pounds per square inch	4.88243	Kilograms per square meter
Pounds per square foot	47.8803	Newtons per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72899	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
Tons (long) per cubic yard	1,329.84	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4869	Grams per liter
Ounces per gallon (U.K.)	8.2328	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.776	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011621	Meter-kilograms
Foot-pounds	1.35582	Meter-kilograms
Foot-pounds per inch	1.35582 x 10 <sup>7</sup>	Centimeter-grams
Ounces-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
Feet per year	0.3048 (exactly)	Meters per second
Miles per hour	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second <sup>2</sup>	0.3048*	Meters per second <sup>2</sup>
FLOW		
Cubic feet per second (second-foot)	0.028317*	Cubic meters per second
Gallons (U.S.) per minute	0.07119	Liters per second
Gallons (U.S.) per minute	0.00309	Liters per second
FORCE*		
Pounds	0.453592*	Kilograms
Pounds	4.4482*	Newtons

Multiply	By	To obtain
WORK AND ENERGY*		
British thermal units (Btu)	0.252*	Kilogram calories
Btu per pound	1,055.06	Joules
Foot-pounds	1.35582*	Joules
POWER		
Horsepower	746.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft <sup>2</sup> deg F (k, thermal conductivity)	1.432	Milliwatts/cm deg C
Btu in./hr ft <sup>2</sup> deg F (C, thermal conductance)	0.1240	Kg cal/hr m <sup>2</sup> deg C
Btu/hr ft <sup>2</sup> deg F (C, thermal resistance)	1.4890*	Kg cal/hr m <sup>2</sup> deg C
Deg F hr ft <sup>2</sup> /Btu (R, thermal resistance)	0.568	Milliwatts/cm <sup>2</sup> deg C
Btu/hr deg F (C, heat capacity)	4.882	Kg cal/hr m <sup>2</sup> deg C
Btu/lb deg F (C, heat capacity)	1.791	Cal/gram deg C
Btu/lb deg F (C, thermal diffusivity)	1.000*	Cal/gram deg C
ft <sup>2</sup> /hr (thermal diffusivity)	0.2581	Cm <sup>2</sup> /sec
	0.09290*	M <sup>2</sup> /hr
WATER VAPOR TRANSMISSION		
Grains/hr ft <sup>2</sup> (water vapor permeance)	16.7	Grams/24 hr m <sup>2</sup>
Permeance (permeability)	0.568	Metric perm
Permeance (permeability)	1.87	Metric perm-centimeters
OTHER QUANTITIES AND UNITS		
Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	304.8*	Liters per square meter per day
Pound-seconds per square foot (viscosity)	4.8824*	Kilogram second per square meter
Square feet per second (viscosity)	0.092903*	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03637	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	9.01162	Milli-ohms per circular mil
Milli-ohms per circular mil	10.7639*	Ohms per square meter
Millamps per square foot	10.7639*	Amperes per square meter
Gallons per square yard	0.1196*	Liters per square meter
Pounds per inch	0.13608*	Kilograms per centimeter



#### ABSTRACT

A collection of photographs and descriptive captions indicates some possible combinations of instruments used by the Hydraulics Branch of the Bureau of Reclamation. The described instrument combinations are not exhaustive, but show the capabilities of instruments purchased on a modest budget. One motive for selecting this equipment was the interchangeability of components. An instrumentation system assembled for a particular study may be reassembled into other systems for different investigations. The equipment includes measurement and recording systems for pressure, electric conductivity, temperature, velocity distribution, flow tracing, boundary shear, surge waves, wave height, and analog to digital conversion.

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Hyd-592

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INSTRUMENTATION FOR HYDRAULIC MEASUREMENTS IN LABORATORY AND FIELD STUDIES. Bur Reclam Lab Rep Hyd-592, Hydraul Br, May 1969. Bureau of Reclamation, Denver, 29 p, 4 fig, 25 photo

DESCRIPTORS--/ hydraulics/ \*instrumentation/ measurement/ conductivity/ \*measuring instruments/ temperature/ pressure/ hydraulic conductivity/ \*recording systems/ velocity meters/ velocity/ \*laboratory equipment/ pressure measuring instruments/ pressure sensors/ \*hydraulic equipment/ hydraulic models/ hydraulic transients/ hydraulic engineering  
IDENTIFIERS--/ instrument transformers/ analog instruments/ analog-to-digital converter/ pressure transducers

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